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U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND

ECBC-TR-386

DOMESTIC PREPAREDNESS PROGRAM: CORN OIL PROTECTION FACTOR (PF) TESTING OF COMMERCIAL AIR-PURIFYING NEGATIVE PRESSURE RESPIRATORS WITH P-100 FILTER CARTRIDGES

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The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorizing documents.

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14. ABSTRACT
Results of performance testing of commercial air-purifying negative pressure respirators (NPR) are described. A series of tests were performed using human subjects to determine the corn oil protection factors of NPR systems.

15. SUBJECT TERMS
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EXECUTIVE SUMMARY

A series of Protection Factor (PF) tests were performed on 12 commercially available respirators. These tests determined the ability of the respirator to keep small particulates out of the respirator oro-nasal cavity and protect the user from biological warfare agents. The particulates used in the test were made up of a corn oil aerosol. Testing occurred over several weeks, and humans were used as the test subjects. Testing involved a standard series of exercises designed to represent the range of movements that stress the face seals of respirators.

All the respirators provided the wearers some protection from the aerosol, and several of them provided excellent protection.

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PREFACE

The work described in this report was authorized under the Expert Assistance (Equipment Test) Program for the U.S. Army Edgewood Chemical Biological Center (ECBC) Homeland Defense Business Unit. This work was started in February 2001 and completed in October 2001.

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1. INTRODUCTION

In 1996, Congress passed Public Law 104-201 (Defense Against Weapons of Mass Destruction Act of 1996), directing the Department of Defense (DoD) to assist other federal, state, and local agencies in enhancing preparedness for terrorist attacks using weapons of mass destruction. The DoD responded by forming the Domestic Preparedness Program that same year. One of the objectives of the Domestic Preparedness Program is to enhance federal, state and local emergency and hazardous material (HAZMAT) response to nuclear, biological and chemical (NBC) terrorism incidents. As part of an effective response, emergency and HAZMAT personnel who are responding to an incident will use personal protective equipment (PPE) to protect them from exposure to chemical agents or biological agents. The specific PPE that would be used by these federal, state and local emergency and HAZMAT personnel would depend upon the situation encountered and what PPE is held in inventory.

For this phase of the program, 12 negative pressure respirators were tested. A negative pressure respirator is a respirator in which the air pressure inside the face piece is negative during inhalation with respect to the ambient air pressure outside the respirator. A tight fitting face piece means a respiratory inlet covering that forms an adequate seal with the face. All tested equipment were fitted with P100 filters which provide the highest amount of protection. There were two types of face pieces tested during this phase; full and half face pieces. A half face piece covers only the nose and mouth region, while a full face piece also covers the eyes.

2. OBJECTIVES AND RESPIRATOR DESCRIPTIONS

The main objective of this project was to determine the protection factors (PF) that reflect leakage for the 12 commercially available respirators using a corn oil aerosol as a biological warfare simulant. These tests evaluated the respirator as a unit, not the filter cartridge alone.

A secondary objective of these tests is to provide enough information to assist potential first responders and other users in selecting appropriate respiratory protection.

The respirators tested in this phase of the project are as follows:

- 3M 6000 Series Full Face w/P-100 Filter Cartridge
- 3M 6000 Series Half Face w/P-100 Filter Cartridge
- NORTH Series 7600 Full Face w/P-100 Filter Cartridge
- NORTH Series 7600 Half Face w/P-100 Filter Cartridge

- MSA Ultra-Twin Full Face w/P-100 Filter Cartridge
- MSA Comfo Classic Half Face w/P-100 Filter Cartridge
- WILLSON Series 6000 Full Face w/P-100 Filter Cartridge
- WILLSON Series 6000 Half Face w/P-100 Filter Cartridge
- SCOTT AV-2000 Full Face w/P-100 Filter Cartridge
- SCOTT Pro-Tech Full Face w/P-100 Filter Cartridge
- SURVIVAIR Full Face Respirator w/P-100 Filter Cartridge
- SURVIVAIR Half Face Respirator w/P-100 Filter Cartridge

3. PROTECTION FACTOR TESTING

3.1 Corn Oil Testing Equipment.

A challenge aerosol concentration of approximately 20-40 mg/m^3, polydispersed corn oil aerosol having a mass median aerodynamic diameter (MMAD) of 0.4-0.6 μ (the Army Standard) was generated in a 10-ft × 10-ft × 32-ft test chamber. The test chamber challenge aerosol was generated by atomizing liquid corn oil at room temperature using a Laskin nozzle. The Laskin nozzle produced a coarse aerosol cloud, which was directed into an impaction plate to remove the larger particles and yield an aerosol in the desired size range. The concentrated aerosol from the generator was diluted with filtered ambient air to control the challenge aerosol concentration in the exposure chamber.

A 6-decade, 45° off-axis light-scattering laser photometer, manufactured by TSI Inc., sampling at a flow rate of 1-2 L/min, was used to quantify concentration of the challenge and the in-mask corn oil aerosols. For a given particle size, the quantity of scattered light is proportional to the aerosol concentration. The photometer converted the quantity of scattered light to a voltage, which was then digitized and recorded by a microcomputer.

The respirator sampling port was connected from the mask's oro-nasal cavity to the photometer with flexible silicone tubing to measure the amount of aerosol penetrating the mask. A Tygon® sampling tube line was connected from the exposure chamber sampling port to the photometer to determine the challenge aerosol concentration. The short lengths of this tubing ensure that there are minimal conduction losses.

3.2 Protection Factor Testing Method.

3.2.1 Test Procedure.

Each respirator was donned by military volunteers and challenged, on separate dates, with the corn oil aerosol. The number of volunteers for each test ranged from 4 to 24, and 8-12 respirators of each model were used. Prior to testing, each test volunteer was given an orientation in which ECBC personnel explained the PF test, and each test volunteer signed a volunteer agreement. The number of trials per model ranged from 24 to 48. Where fewer trials are reported it is because the test data were invalidated for some reason unrelated to the

respirator design. The minimum number of trials necessary to give a statistical validity or 90% reliability at a 90% confidence level is 22. Additional trials may have been performed simply to provide a larger sample.

All volunteers had anthropometrical measurements taken of their facial features to ensure that they fit the sizing criteria developed by the manufacturer, and then they were given a respirator and asked to wear their normal clothing (Battle Dress Uniform (BDU)). The test volunteers were then led into the aerosol exposure chamber, 8 at a time, by ECBC personnel, hooked up to their photometer stations, and asked to perform a standard Army PF Test devised to stress the face seal of the respirator, namely, the following exercises for 1-min each:

- Normal Breathing
- Deep Breathing
- Turn Head Side to Side
- Move Head Up and Down
- Recite the Rainbow Passage (Reading a paragraph aloud to stress talking)
- Sight the Rifle
- Reach for the Floor and Ceiling
- On Hands and Knees, Turn Head Side to Side
- Facial Expressions
- Normal Breathing

The test equipment operator monitored and communicated with the test volunteers on when to start an exercise, finish an exercise, and exit the aerosol chamber, and monitored their performance. All exercises were completed by the test volunteers without the intervention of test personnel. The raw data was collected by a computer-based system and stored for later analysis.

3.2.2 Data Analysis.

Mask performance was quantified in terms of a protection factor (PF). As stated earlier, this test evaluated the ability of the equipment to seal to the subject's face. The PF was determined by calculating the ratio of the challenge aerosol concentration to the in-mask aerosol concentration, as quantified by integrating the peak voltage output from the photometer over the time interval (nominally 1-min). For example, if a subject has a PF of 10,000, the air they are breathing is 10,000 times cleaner than the air outside of the respirator. A PF was calculated for individual exercises (PF_i). The individual PFs were then used to calculate an overall PF for a subject (PF_o) as follows:

$$PF_o = n\left(\sum_{i=1}^{n}\frac{1}{PF_i}\right)^{-1}$$

where n is the number of exercises. The overall PF provides a time-integrated measure of the protection afforded. It is somewhat analogous to calculating the total resistance of resistors in

parallel in an electronic circuit. The PF_0 is affected most by the smallest PFs. Under the conditions of this test, including the sensitivity of the photometer, the maximum PF that can be reported is 100,000.

3.3 Test Results.

The test data are summarized below in Tables 1 - 12. The first column lists the lower limit of each range of PF computed. The second column is the number of test trials falling within each calculated PF range. The third column presents the cumulative-percentage of test trials that resulted in a PF below the lower limit of the range and the fourth column presents the percentage of trials that exceed the lower limit of the range shown. A PF value measured may have been over 100,000, but the current data acquisition system cannot measure PF over 100,000, so it truncates the data and puts all the remaining subjects in the final range.

Table 1. 3M 6000 Series Full Face with P-100 Filter Cartridge

PF	Frequency*	Cumulative %	Pass %
0	0	.00	100.00
10	0	.00	100.00
50	0	.00	100.00
100	0	.00	100.00
500	1	3.13	96.88
1000	0	3.13	96.88
1667	1	6.25	93.75
2000	1	9.38	90.63
5000	4	21.88	78.13
6667	1	25.00	75.00
10000	1	28.13	71.88
20000	0	28.13	71.88
50000	3	37.50	62.50
100000	20	100.00	.00

*Total Trials = 32

Text continues on page 18.

Table 2. 3M 6000 Series Half Face with P-100 Filter Cartridge

PF	Frequency*	Cumulative %	Pass %
0	0	.00	100.00
10	0	.00	100.00
50	3	12.50	87.50
100	0	12.50	87.50
500	6	37.50	62.50
1000	1	41.67	58.33
1667	1	45.83	54.17
2000	0	45.83	54.17
5000	1	50.00	50.00
6667	1	54.17	45.83
10000	1	58.33	41.67
20000	2	66.67	33.33
50000	4	83.33	16.67
100000	4	100.00	.00

*Total Trials = 24

Table 3. NORTH Series 7600 Full Face with P-100 Filter Cartridge

PF	Frequency*	Cumulative %	Pass %
0	0	.00	100.00
10	0	.00	100.00
50	0	.00	100.00
100	0	.00	100.00
500	4	12.50	87.50
1000	0	12.50	87.50
1667	1	15.63	84.38
2000	0	15.63	84.38
5000	1	18.75	81.25
6667	0	18.75	81.25
10000	0	18.75	81.25
20000	6	37.50	62.50
50000	3	46.88	53.13
100000	17	100.00	.00

*Total Trials = 32

Table 4. NORTH Series 7700 Half Face with P-100 Filter Cartridge

PF	Frequency*	Cumulative %	Pass %
0	0	.00	100.00
10	0	.00	100.00
50	1	4.17	95.83
100	0	4.17	95.83
500	1	8.33	91.67
1000	0	8.33	91.67
1667	0	8.33	91.67
2000	0	8.33	91.67
5000	1	12.50	87.50
6667	2	20.83	79.17
10000	2	29.17	70.83
20000	1	33.33	66.67
50000	3	45.83	54.17
100000	13	100.00	.00

*Total Trials = 24

Table 5. MSA Ultra-Twin Full Face with P-100 Filter Cartridge

PF	Frequency*	Cumulative %	Pass %
0	0	.00	100.00
10	0	.00	100.00
50	0	.00	100.00
100	0	.00	100.00
500	0	.00	100.00
1000	0	.00	100.00
1667	0	.00	100.00
2000	0	.00	100.00
5000	2	6.25	93.75
6667	1	9.38	90.63
10000	0	9.38	90.63
20000	2	15.63	84.38
50000	2	21.88	78.13
100000	25	100.00	.00

*Total Trials = 32

Table 6. MSA Comfo Classic Half Face with P-100 Filter Cartridge

PF	Frequency*	Cumulative %	Pass %
0	0	.00	100.00
10	2	8.33	91.67
50	6	33.33	66.67
100	5	54.17	45.83
500	3	66.67	33.33
1000	3	79.17	20.83
1667	1	83.33	16.67
2000	0	83.33	16.67
5000	0	83.33	16.67
6667	0	83.33	16.67
10000	0	83.33	16.67
20000	0	83.33	16.67
50000	1	87.50	12.50
100000	3	100.00	.00

*Total Trials = 24

Table 7. WILLSON Series 6000 Full Face with P-100 Filter Cartridge

PF	Frequency	Cumulative %	Pass %
0	0	.00	100.00
10	1	3.13	96.88
50	3	12.50	87.50
100	0	12.50	87.50
500	2	18.75	81.25
1000	6	37.50	62.50
1667	0	37.50	62.50
2000	0	37.50	62.50
5000	1	40.63	59.38
6667	0	40.63	59.38
10000	2	46.88	53.13
20000	1	50.00	50.00
50000	6	68.75	31.25
100000	10	100.00	.00

*Total Trials = 32

Table 8. WILLSON Series 6000 Half Face with P-100 Filter Cartridge

PF	Frequency*	Cumulative %	Pass %
0	0	.00	100.00
10	0	.00	100.00
50	0	.00	100.00
100	0	.00	100.00
500	3	12.50	87.50
1000	4	29.17	70.83
1667	3	41.67	58.33
2000	2	50.00	50.00
5000	6	75.00	25.00
6667	0	75.00	25.00
10000	0	75.00	25.00
20000	1	79.17	20.83
50000	1	83.33	16.67
100000	4	100.00	.00

*Total Trials = 24

Table 9. SCOTT AV-2000 Full Face with P-100 Filter Cartridge

PF	Frequency*	Cumulative %	Pass %
0	0	.00	100.00
10	7	14.58	85.42
50	7	29.17	70.83
100	2	33.33	66.67
500	8	50.00	50.00
1000	0	50.00	50.00
1667	2	54.17	45.83
2000	0	54.17	45.83
5000	1	56.25	43.75
6667	0	56.25	43.75
10000	1	58.33	41.67
20000	1	60.42	39.58
50000	6	72.92	27.08
100000	13	100.00	.00

*Total Trials = 48

Table 10. SCOTT Pro-Tech Full Face with P-100 Filter Cartridge

PF	Frequency*	Cumulative %	Pass %
0	0	.00	100.00
10	0	.00	100.00
50	0	.00	100.00
100	1	3.13	96.88
500	19	62.50	37.50
1000	4	75.00	25.00
1667	2	81.25	18.75
2000	1	84.38	15.63
5000	1	87.50	12.50
6667	0	87.50	12.50
10000	4	100.00	.00
20000	0	100.00	.00
50000	0	100.00	.00
100000	0	100.00	.00

*Total Trials = 32

Table 11. SURVIVAIR Full Face Respirator w/P-100 Filter Cartridge

PF	Frequency*	Cumulative %	Pass %
0	0	.00	100.00
10	0	.00	100.00
50	0	.00	100.00
100	0	.00	100.00
500	0	.00	100.00
1000	0	.00	100.00
1667	0	.00	100.00
2000	0	.00	100.00
5000	3	9.09	90.91
6667	1	12.12	87.88
10000	1	15.15	84.85
20000	0	15.15	84.85
50000	1	18.18	81.82
100000	27	100.00	.00

*Total Trials = 33

Table 12. SURVIVAIR Half Face Respirator w/P-100 Filter Cartridge

PF	Frequency*	Cumulative %	Pass %
0	0	.00	100.00
10	0	.00	100.00
50	0	.00	100.00
100	2	8.33	91.67
500	4	25.00	75.00
1000	2	33.33	66.67
1667	2	41.67	58.33
2000	0	41.67	58.33
5000	2	50.00	50.00
6667	1	54.17	45.83
10000	1	58.33	41.67
20000	2	66.67	33.33
50000	1	70.83	29.17
100000	7	100.00	.00

*Total Trials = 24

4. SUMMARY

Protection factor (PF) testing was performed in accordance with the U.S. Army PF testing standard (available upon request) for negative pressure respirators (see Table 13) used in a biological environment. The tables provided in this report should help first responders and the emergency communities make good choices in picking the best respirator with the best performance. Other criteria, including cost, are always important when choosing the best respirator for the job, but they were not evaluated in this test.

Table 13. Pass Percentages for Negative Pressure Respirators at Selected PF Levels

	Pass Rate, %				
Respirator	PF 100	PF 1667	PF 6667	PF 10,000	PF 50,000
3M 6000 Series Full Face	100	94	75	72	63
3M 6000 Series Half Face	88	54	46	42	17
NORTH Series 7600 Full Face	100	84	81	81	53
NORTH Series 7600 Half Face	96	92	79	71	54
MSA Ultra-Twin Full Face	100	100	91	91	78
MSA Comfo Classic Half Face	46	21	17	17	13
WILLSON Series 6000 Full Face	88	63	59	53	31
WILLSON Series 6000 Half Face	100	58	25	25	17
SCOTT AV-2000 Full Face	67	46	44	42	27
SCOTT Pro-Tech Full Face	97	25	19	0	0
SURVIVAIR Full Face Respirator	100	100	88	85	82
SURVIVAIR Half Face Respirator	92	58	46	42	29

GLOSSARY

Anthropometric Facial Measurements

These are measurements of a human subject's face. The most commonly measured areas are facial length and width.

APR

Air Purifying Respirator

Cartridge

A container filled with sorbents, catalysts, and/or filters that removes gases, vapors, and/or particulates from air drawn through the unit.

Exhalation Valve

A device that allows exhaled air to leave a respiratory device and prevents outside air from entering through the valve while inhaling.

Face Piece

The portion of a respirator that covers the wearer's nose and mouth (a full face piece also covers the eyes). The face piece should make a gas-tight or dust-tight seal with the face. The face piece is supported by headbands, and contains inhalation valves, exhalation valves, and connectors for the air-purifying cartridges or filters.

Filter

A fibrous medium used in respirators to remove solid or liquid particulates from the air before they enter the face piece. Some filter types contain vapor/gas purifying elements (this term may be used interchangeably with cartridge).

Inhalation Valve

A device that allows air to enter the face piece through the filtering media but prevents exhaled air from leaving the face piece through the intake openings.

P-100 Filter Cartridges

A filter type, which has a high efficiency for capturing particles.

Particulate Matter

A suspension of fine solid or liquid particles in air, i.e., dust, fog, fume, smoke, or sprays. Particulate matter suspended in air is commonly known as an aerosol.

Protection Factor (PF)

The ratio of the concentration of particles outside to the concentration of particles inside protective equipment.